Reinhold Environmental Ltd.

2007 APC Round Table & Expo Presentation

July 8-10, 2007
Chattanooga, TN
Hosted by TVA

Wet FGD
Operations and Maintenance Workshop

Greg Bielawski
The Babcock & Wilcox Company

Gordon Maller
URS Corporation

Tony Licata
Babcock Power Environmental

Richard Staehle
Marsulex

Melissa Allen
TVA

Bob Candelaria
Salt River Project

Hans Hartenstein
STEAG, LLC

Ron Richard
RE Consulting

Scott Williams
Duke Energy

APC / PCUG Conference
July 8, 2007

Workshop Outline

1. Wet FGD Process Description, Equipment, Configuration, Materials
2. Chemistry Overview, Effect of Key Process Variables, Process Problems – Identify and Correct, Optimization of System Performance
3. Equipment Operation and Maintenance
4. Panel Discussion

Workshop Outline

1. **Wet FGD Process Description, Equipment, Configuration, Materials**
2. **Chemistry Overview, Effect of Key Process Variables, Process Problems – Identify and Correct, Optimization of System Performance**
3. **Equipment Operation and Maintenance**
4. **Panel Discussion**

Workshop Outline

1. Wet FGD Process Description, Equipment, Configuration, Materials

What's the issue & progress
Overview of major types of utility FGD systems
General description of wet limestone forced oxidized (LSFO) system
Basic types & configurations of commercially available LSFO FGD technology
Absorber Configuration, Equipment, Materials
Forced Oxidation / Dewatering, Milling System

Workshop Outline

1. Wet FGD Process Description, Equipment, Configuration, Materials

What's the issue & progress

Overview of major types of utility FGD systems

General description of wet limestone forced oxidized (LSFO) system

Basic types & configurations of commercially available LSFO FGD technology

Absorber Configuration, Equipment, Materials

Forced Oxidation / Dewatering, Milling System

What is the driver to scrub?

Past

- Coarse particulate
- Acid rain
  - Scrubbers for sulfur oxides as sulfuric acid precursors
  - Combustion control for nitrogen oxides as nitric acid precursors

Present

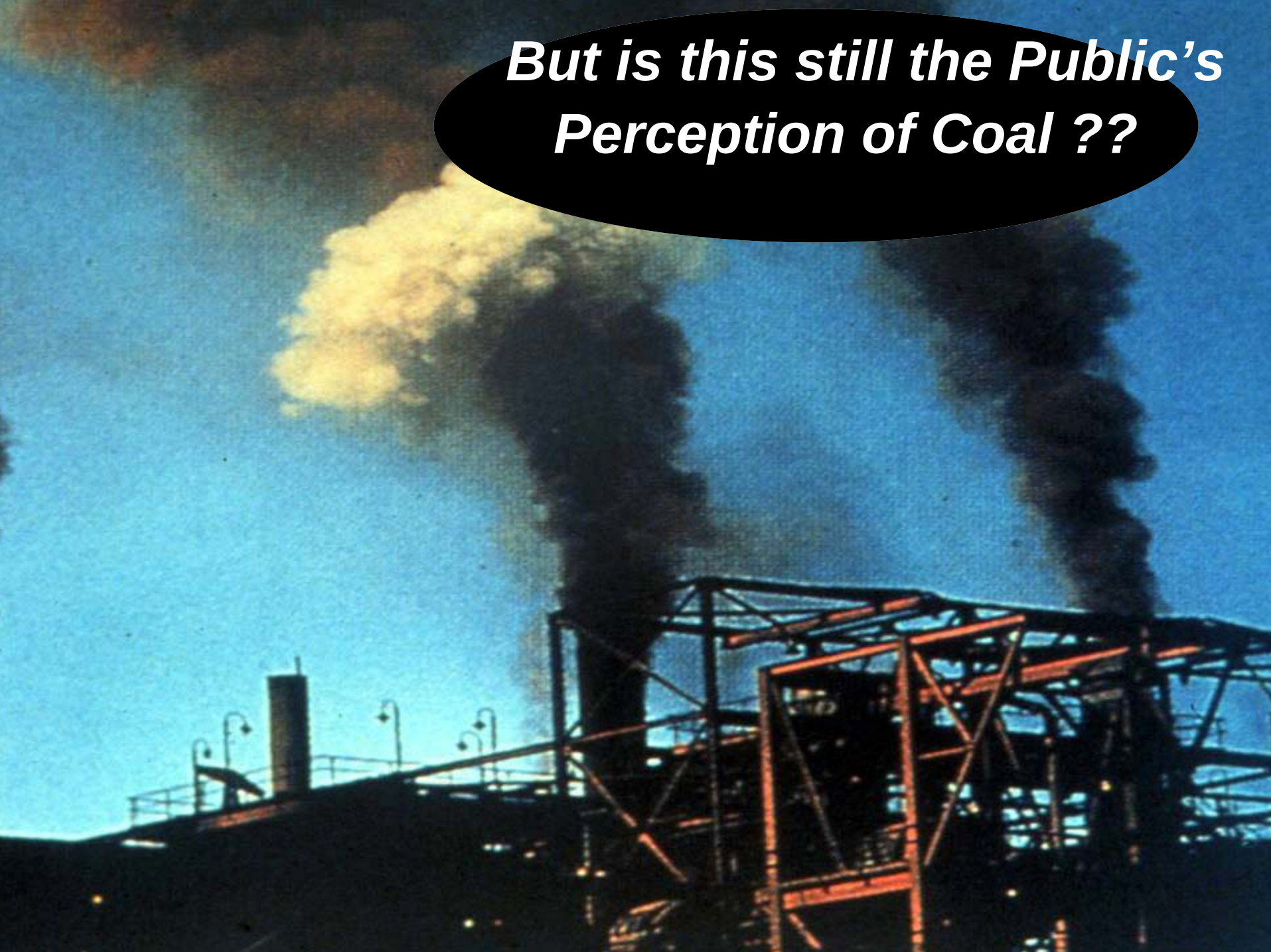
- Acid rain
  - By-product utilization of sulfur oxides
  - Selective catalytic reduction for nitrogen oxides as nitric acid precursors
- Air toxics, especially mercury
- PM 2.5 (fine particulate matter less than 2.5 microns)
- Sulfuric Acid Mist

Coming Soon

- Carbon dioxide controls

U.S. Legislative Drivers

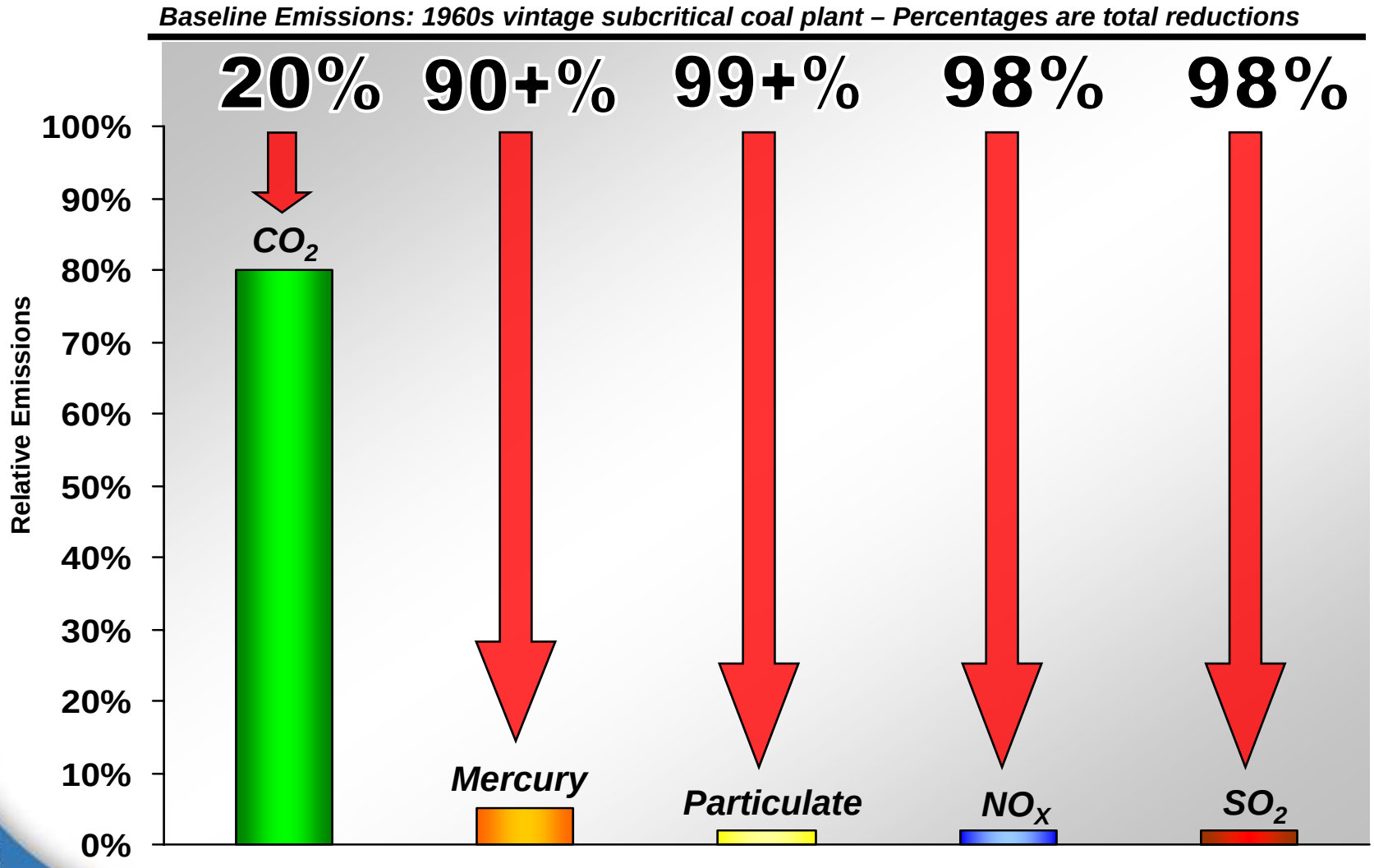
- Clean Air Act of 1970
- Clean Air Act Amendment of 1977
- Clean Air Act Amendments of 1990
  - Phase I - January 1995
  - Phase II - January 2000
- PM 2.5 / Ozone Regulations
- Clean Air Interstate Rule (CAIR)
- Clean Air Mercury Rule (CAMR)
- Clean Air Visibility Rule (CAVR)
- CO_2 Limits (TBD)


But is this still the Public's
Perception of Coal ??

The Modern Look of Coal-Fired Power Generation

Tri-State Generation – Craig, Colorado

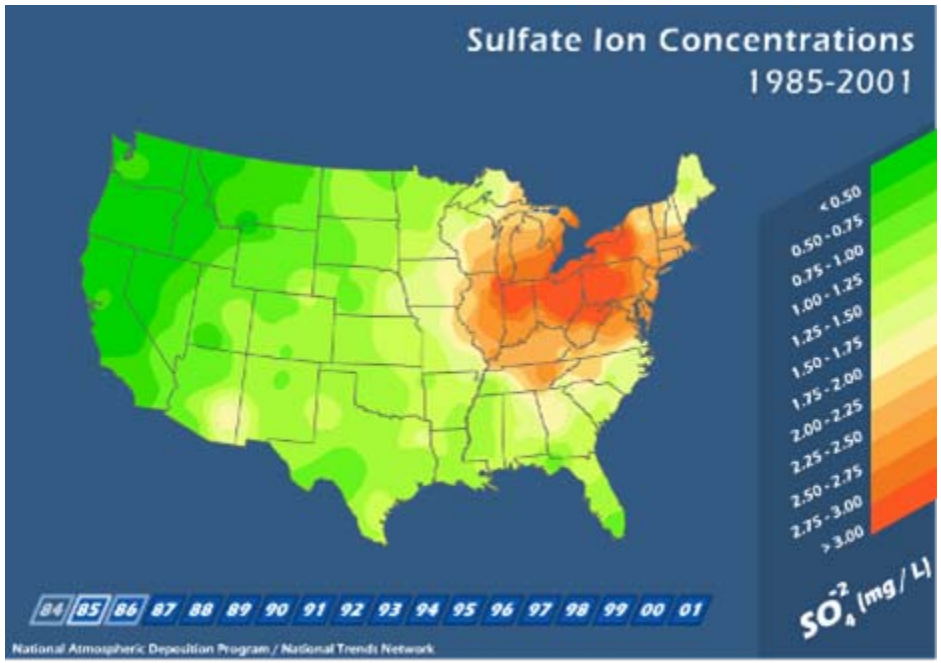
New Pulverized Coal Plants Significantly Reduce Emissions



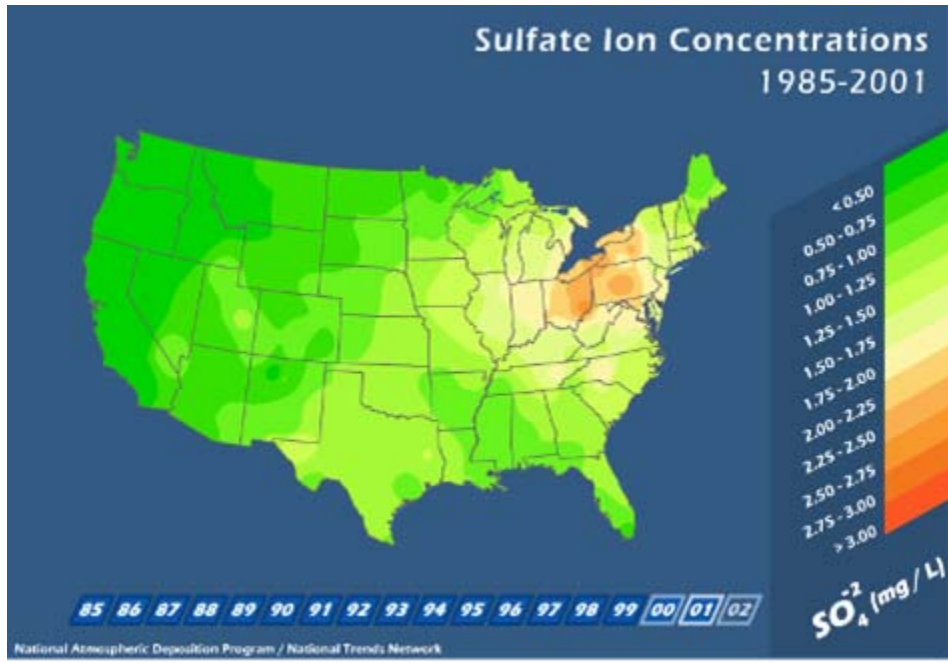
Is the USA making progress?

Wet Sulfate Deposition

1985



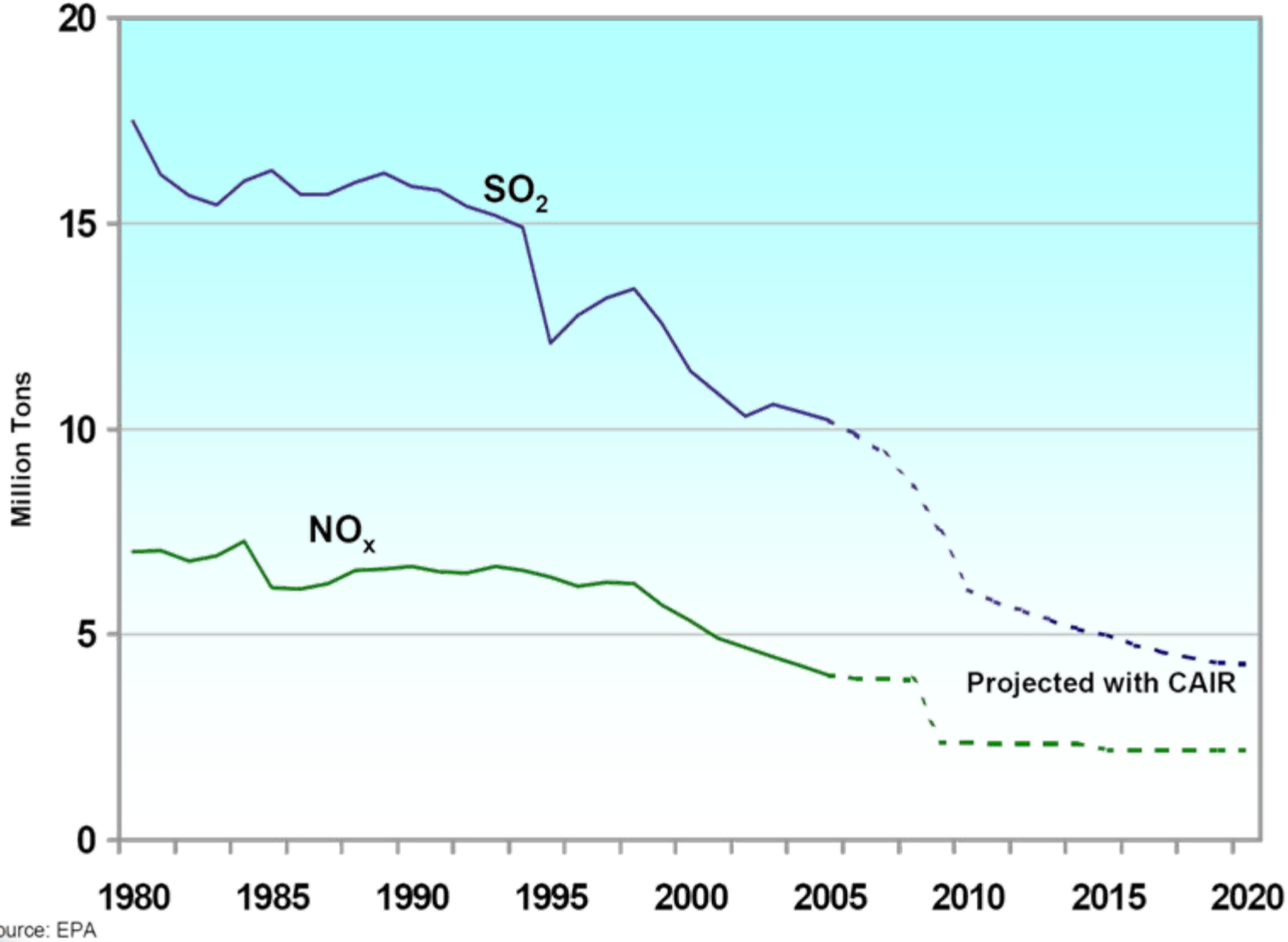
2001



Source: EPA

CAIR Accelerates 35 Years of Clean Air Progress:

Nationwide SO_2 and NO_X Emissions from the Power Sector

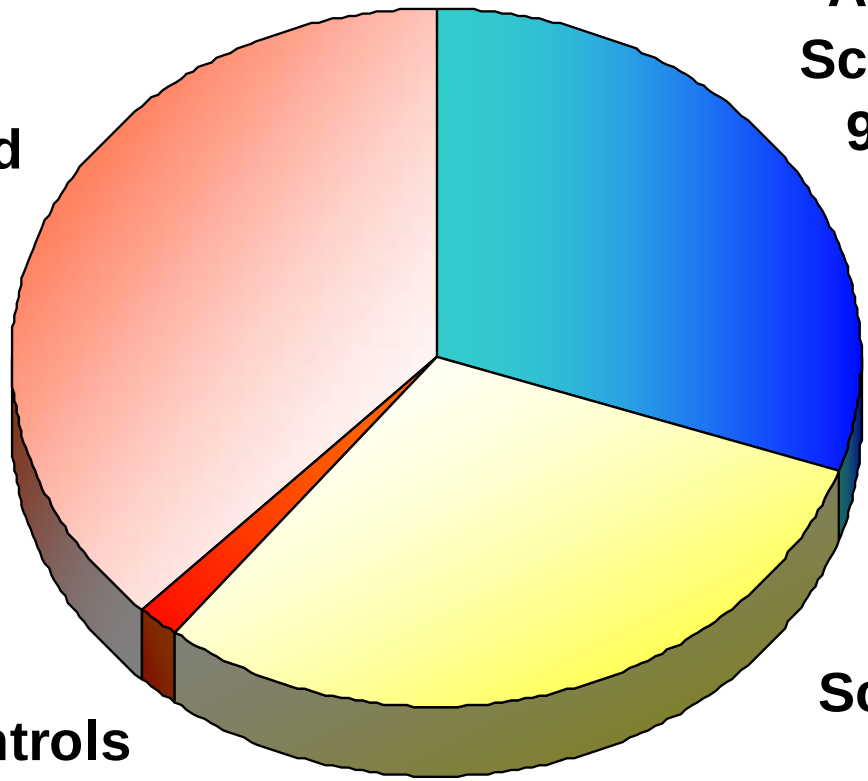


Source: EPA

Reactions to SO_2 Regulations

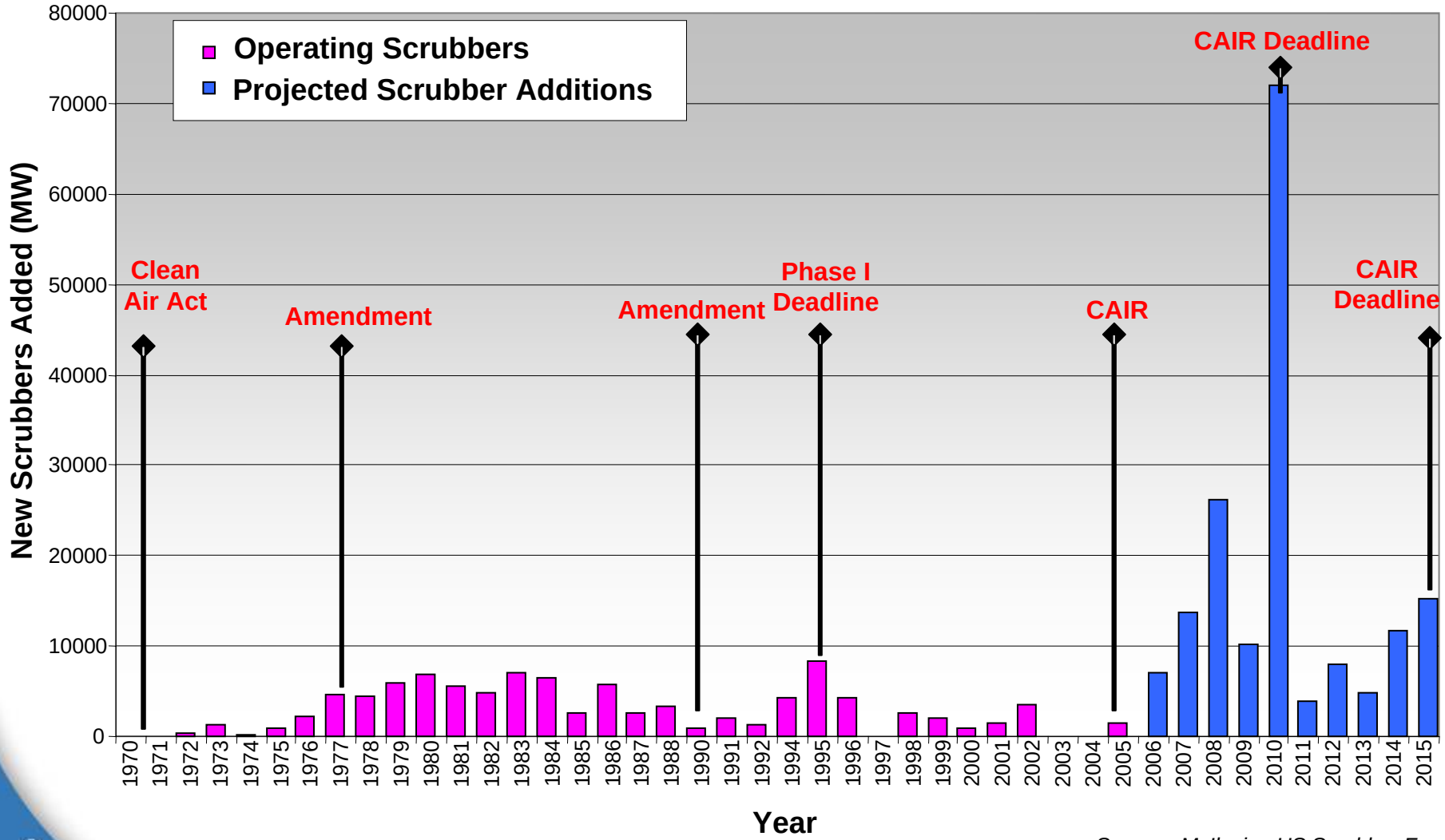
- **Buy credits**
- **Switch to lower sulfur coals**
  - **Powder River Basin**
- **Install scrubbers**
  - **Dry scrubbers - lower sulfur applications**
  - **Wet scrubbers - higher sulfur applications**
- **Earn credits / bank credits / sell credits**
- **Upgrades to Existing Scrubbers to Increase SO_2 Removal.**

U.S. Coal-Fired Generating Capacity by Scrubber Status



328 GW Total

Utility FGD Additions by Year



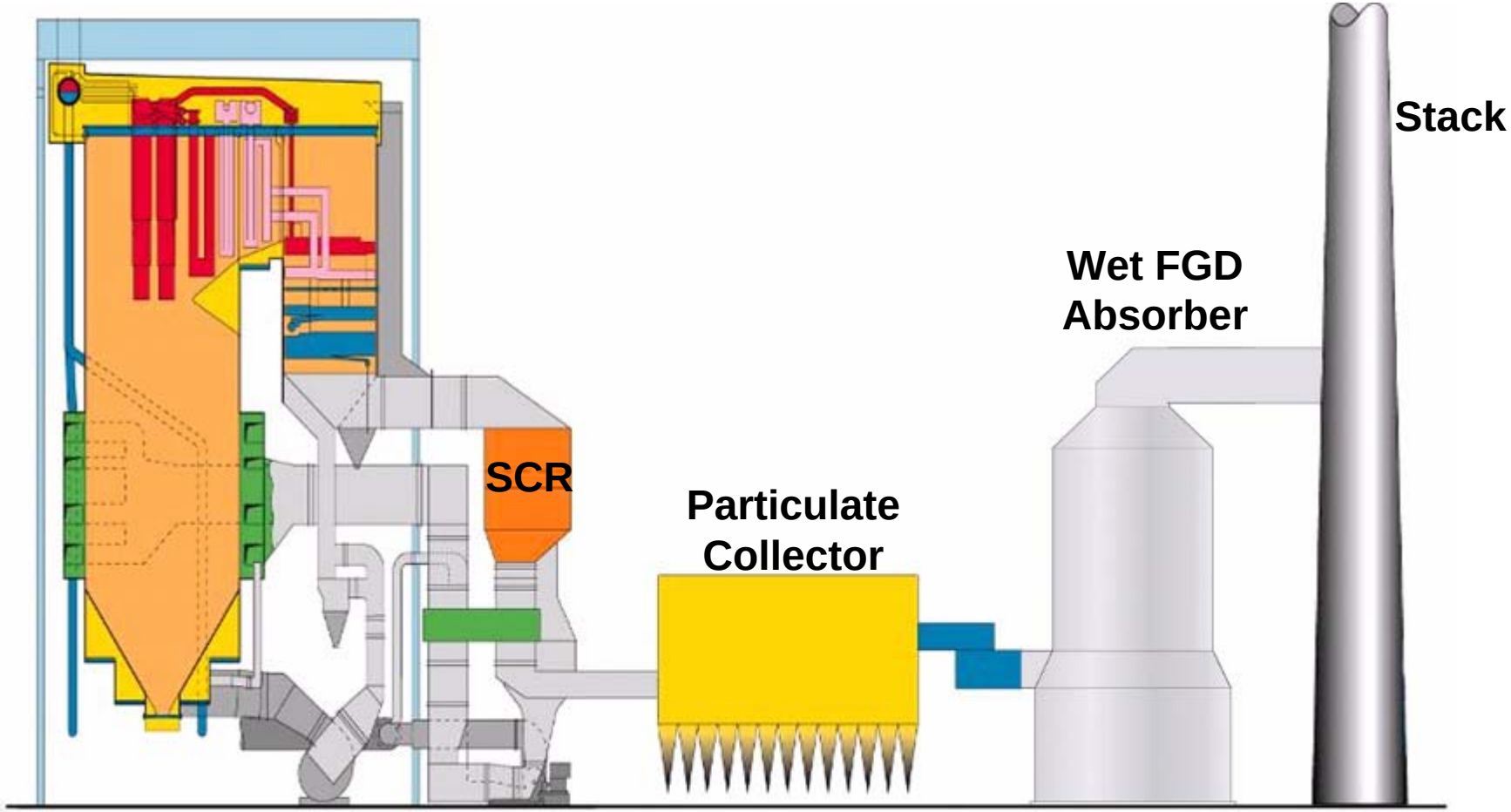
Source : McIlvaine US Scrubber Forecast

Workshop Outline

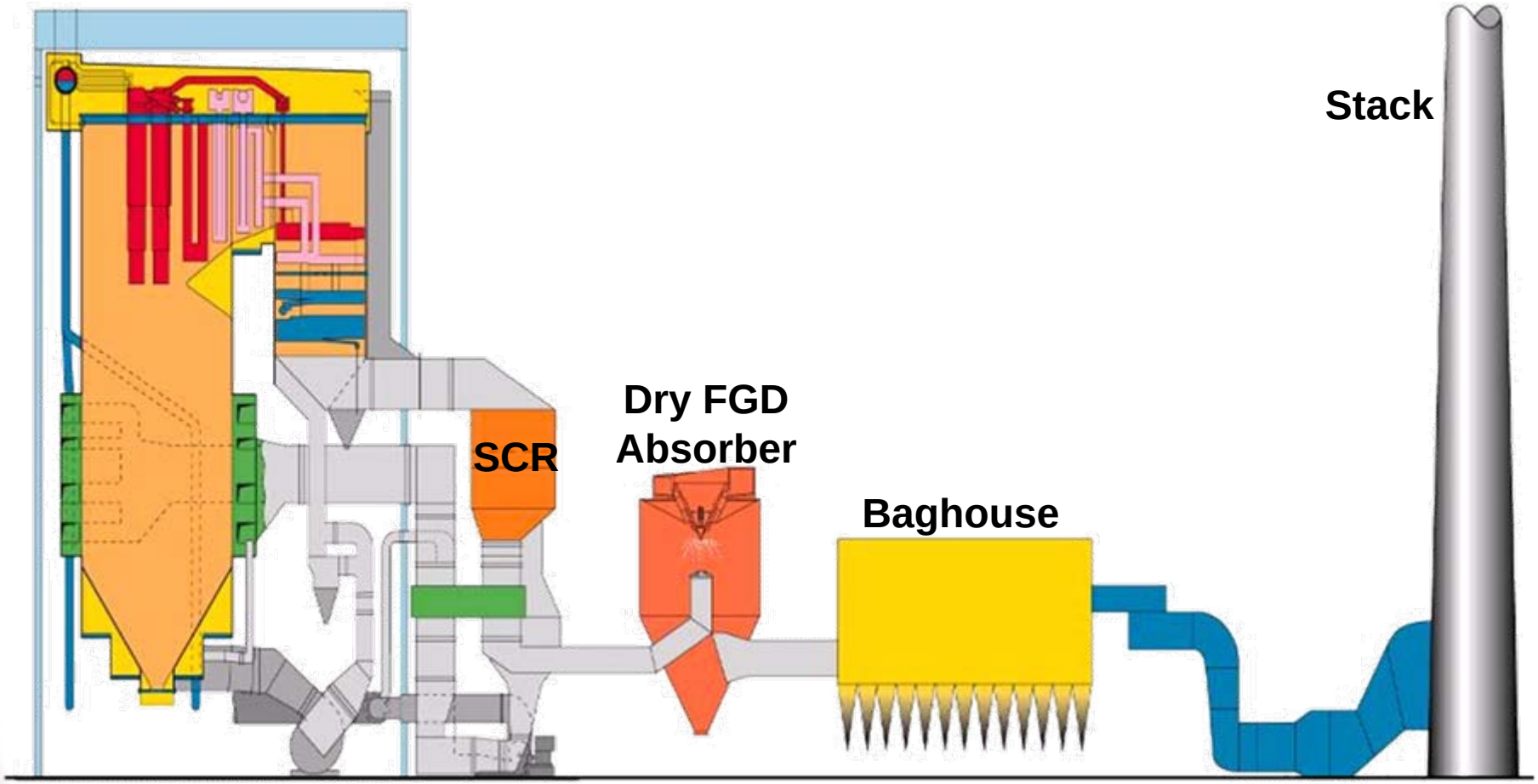
1. Wet FGD Process Description, Equipment, Configuration, Materials

- **What's the issue & progress**
- **Overview of major types of utility FGD systems**
- **General description of wet limestone forced oxidized (LSFO) system**
- **Basic types & configurations of commercially available LSFO FGD technology**
- **Absorber Configuration, Equipment, Materials**
- **Forced Oxidation / Dewatering, Milling System**

Typical High Sulfur Coal Configuration



Typical Low Sulfur Coal (i.e. PRB) Configuration



Sulfur in Coal to SO_2

3.0% Sulfur; 12,000 BTU/LB coal

$$\frac{3.0 \text{ lb Sulfur}}{100 \text{ lb coal}} \times \frac{1 \text{ mole Sulfur}}{32 \text{ lb Sulfur}} \times \frac{1 \text{ mole } SO_2}{1 \text{ mole Sulfur}} \times$$

$$\frac{64 \text{ lb } SO_2}{1 \text{ mole } SO_2} \times \frac{1 \text{ lb coal}}{12{,}000 \text{ BTU}} \times \frac{1{,}000{,}000 \text{ BTU}}{\text{Million BTU}}$$

$$= 5.0 \ \frac{\text{lb } SO_2}{\text{Million BTU}}$$

Also known as a "5 Lb Coal"

~2624 ppmvd @ 3% O_2 (parts per million by volume dry at 3% oxygen in the flue gas); ~525 ppm SO_2 per 1 lb Coal

~6240 mg per DSCM @ 6%O_2 (milligrams per dry standard cubic meter, 0 degrees C) (2.38 x ppm)

Wet FGD Chemistry - Limestone

2 lbs. SO_2 for each 1 lb. of sulfur in fuel

$$CaCO_3 + SO_2 + 2\,H_2O + {}^1/_2O_2 \longrightarrow CaSO_4 \cdot 2H_2O + CO_2$$

Calcium Carbonate (limestone)

Calcium Sulfate or gypsum
(primary material in wallboard)

Dry FGD Chemistry - Lime

$$CaO + SO_2 + 0.5\,H_2O \longrightarrow CaSO_3 \cdot 0.5H_2O$$

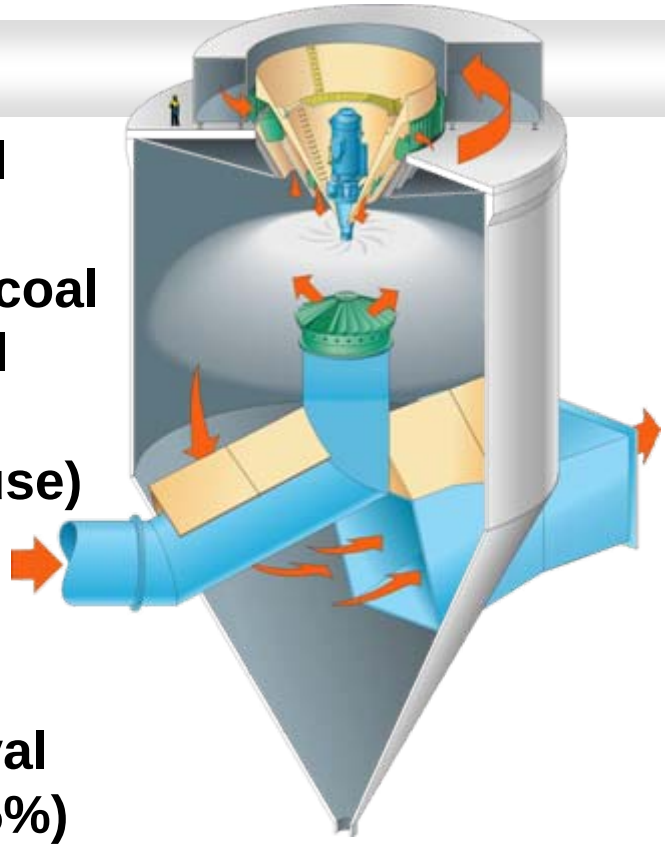
Calcium Oxide (lime)

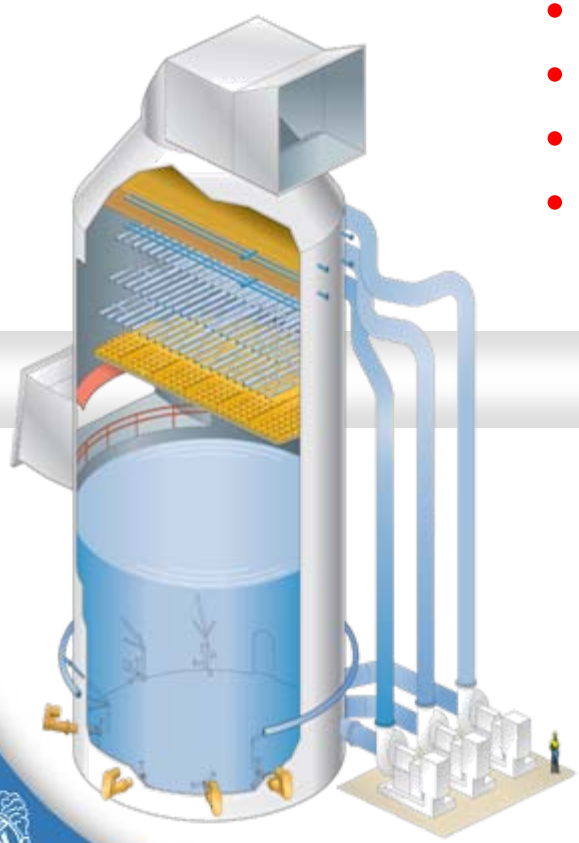
Calcium Sulfite – to minefill

SO_2 Reduction with Wet FGD or Dry FGD

Dry FGD System

- Up to 95% SO_2 removal
- Lower sulfur fuels
- Typically <1.5% sulfur coal
- Dry product for landfill
- Uses lime ($50-70/ton)
- Final filter last (baghouse)





Wet FGD System

- Up to 98% SO_2 removal
- High sulfur fuels(>1.5%)
- More fuel flexibility
- Marketable byproduct
- Typically uses limestone ($5-15/ton)

Workshop Outline

1. Wet FGD Process Description, Equipment, Configuration, Materials

- What's the issue & progress
- Overview of major types of utility FGD systems
- General description of wet limestone forced oxidized (LSFO) system
- Basic types & configurations of commercially available LSFO FGD technology
- Absorber Configuration, Equipment, Materials
- Forced Oxidation / Dewatering, Milling System

Characteristics of Wet FGD Systems

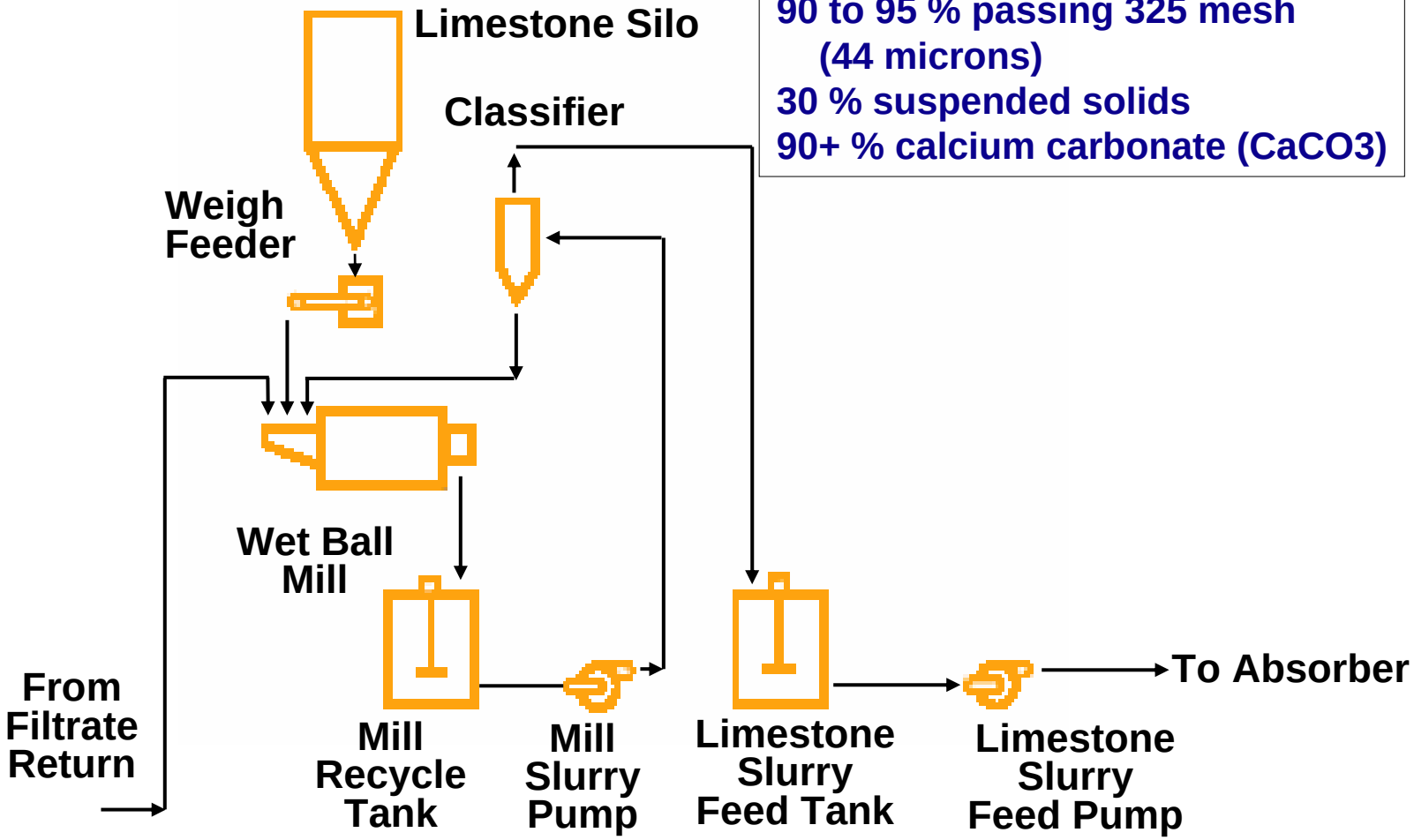
- **Coal sulfur levels of 0.2 to 8 %**
- **Inlet SO_2 ranges from 200 - 6500 ppmv**
- **Removal efficiencies up to 99 %**
- **98% removal typically required today**
- **Mature Technology: 4th Generation**
- **One tower per boiler; even 1300 MW units**
- **Added benefit: ability to remove oxidized mercury**
- **Availability better than the boiler today**

Wet FGD Process Overview

- Prepare reagent (such as limestone, lime, or soda ash)
- Quench / Humidify the Flue Gas
- Absorb SO_2
- React SO_2 with reagent
- Oxidize to Gypsum
- Remove slurry from flue gas
- Separate product (ie, gypsum) from water slurry (dewater)

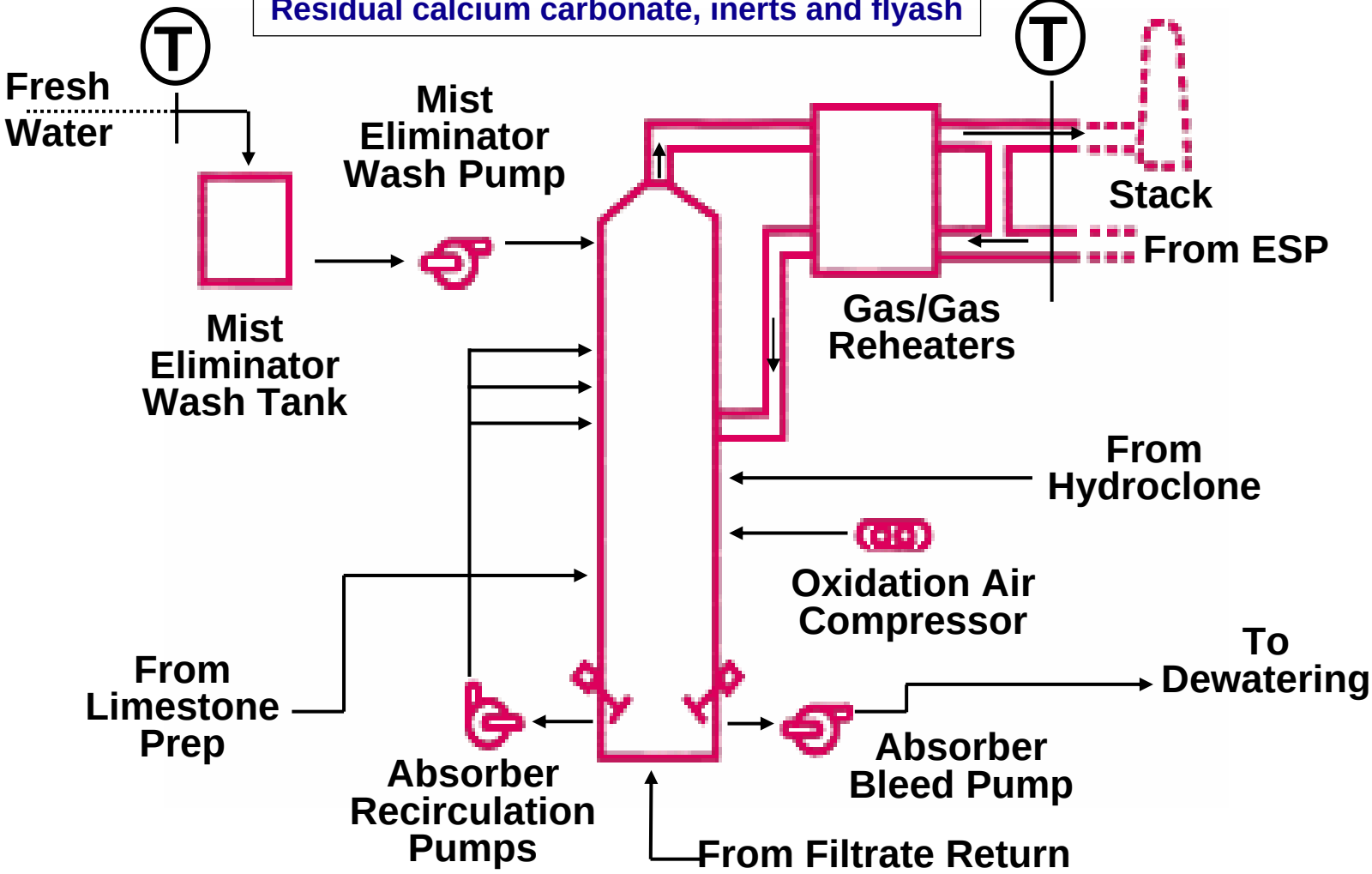
Limestone Preparation System

Limestone feed
90 to 95 % passing 325 mesh (44 microns)
30 % suspended solids
90+ % calcium carbonate ($CaCO_3$)



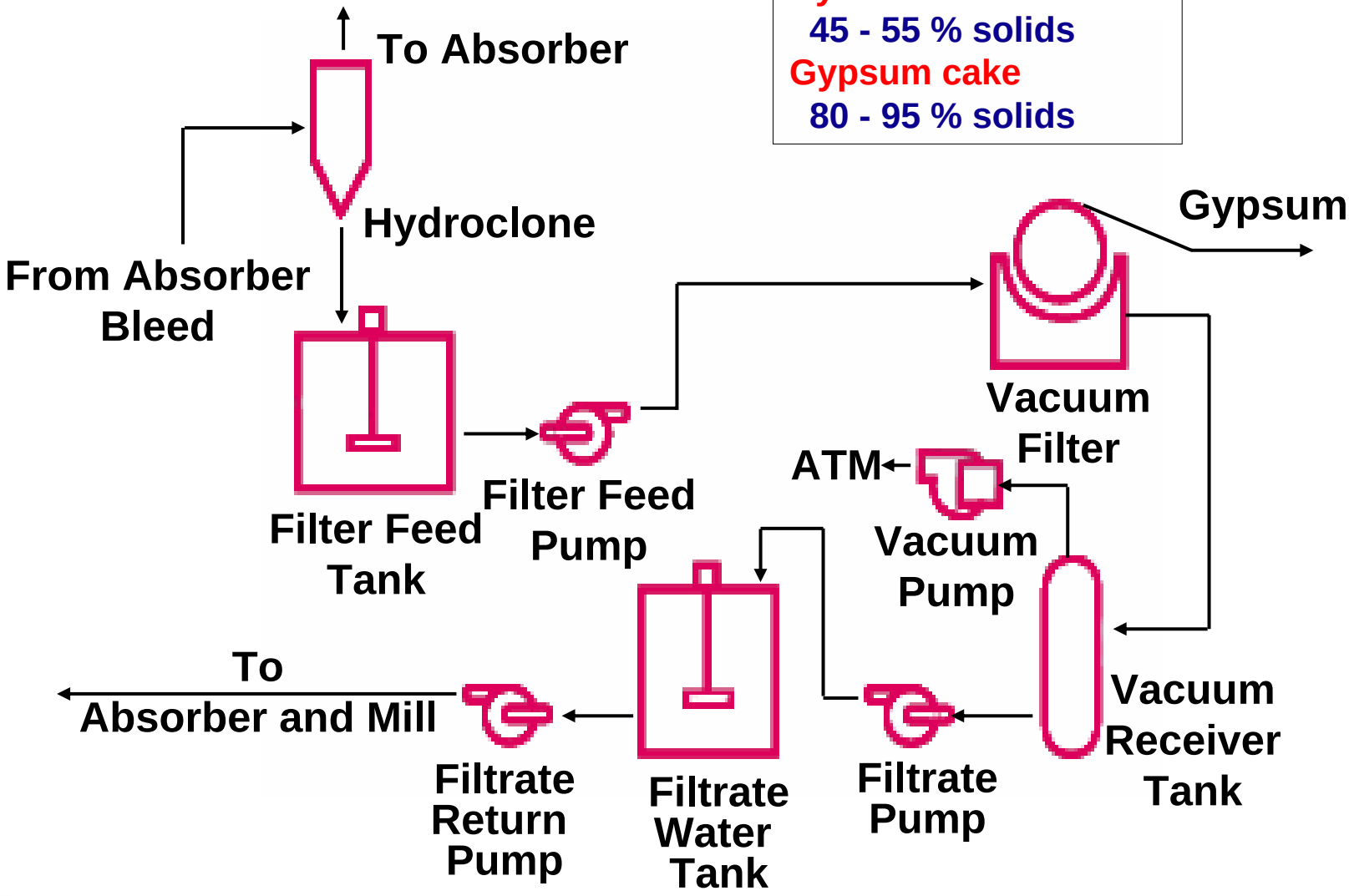
Absorber System

Absorber slurry
15 - 20 % suspended solids
92%+ gypsum (calcium sulfate, $CaSO_4 \cdot 2H_2O$)
Residual calcium carbonate, inerts and flyash



Dewatering System

Absorber Bleed
15 - 20 % solids
Hydroclone underflow
45 - 55 % solids
Gypsum cake
80 - 95 % solids



Wet FGD Equipment Terminology

Reagent Preparation - A system for preparing the reagent slurry used for sulfur dioxide (SO_2) removal, typically with grinding mills for limestone or slakers for lime.

Absorber or Absorber Tower - Also called a scrubber, the vessel where the flue gas passes through a slurry spray for SO_2 absorption and removal.

Absorber Spray - A system of spray nozzles to administer a distributed spray of slurry within the absorber tower.

Contact Device - A perforated plate installed in the absorber to increase contact between the flue gas and the slurry.

Recirculation Tank - A vessel which receives and stores the slurry which has been sprayed into an absorber. The slurry from this tank is recirculated to the spray nozzles.

Mist Eliminator - A device used to separate slurry droplets from the scrubbed flue gas at the absorber outlet.

See Lexicon

Workshop Outline

1. Wet FGD Process Description, Equipment, Configuration, Materials

What's the issue & progress
Overview of major types of utility FGD systems
General description of wet limestone forced oxidized (LSFO) system
Basic types & configurations of commercially available LSFO FGD technology
Absorber Configuration, Equipment, Materials
Forced Oxidation / Dewatering, Milling System

Wet FGD Absorber Types

Configuration

- Open Spray Tower
- Spray Tower with Tray
- Double Contact Flow Scrubber
- Bubbling reactor
- Packed tower

Method

- Once-through
- Regenerable

Reagent

- Calcium-based - limestone or lime
- Sodium-based - soda ash, caustic soda

Wet FGD Absorber Types

Configuration

- Open spray tower
- Spray tower with Tray
- Double Contact Flow Scrubber
- Bubbling reactor
- ~~Packed tower~~

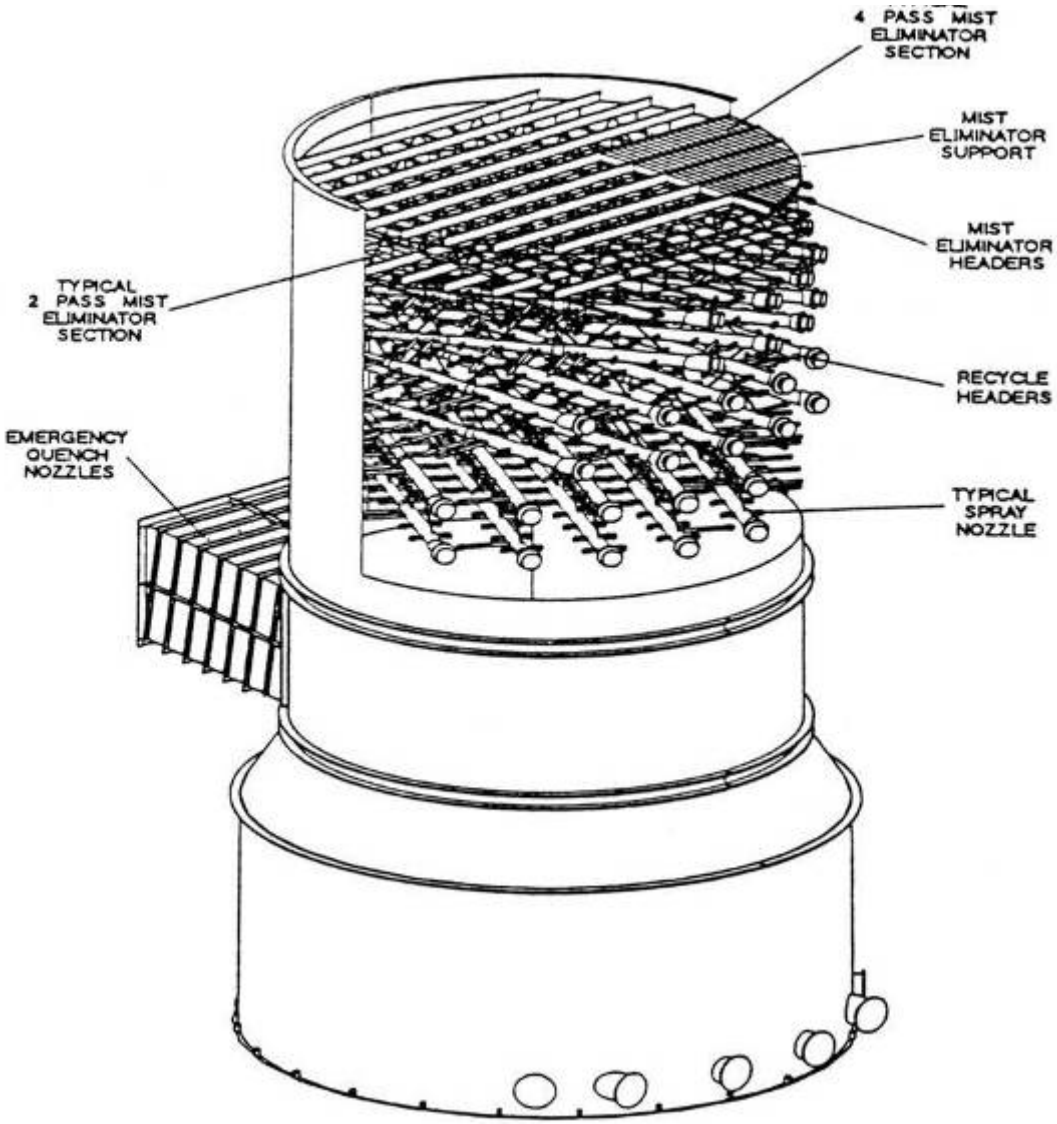
Method

- Once-through
- ~~Regenerable~~

Reagent

- Calcium-based - limestone or lime
- Sodium-based - soda ash, caustic soda

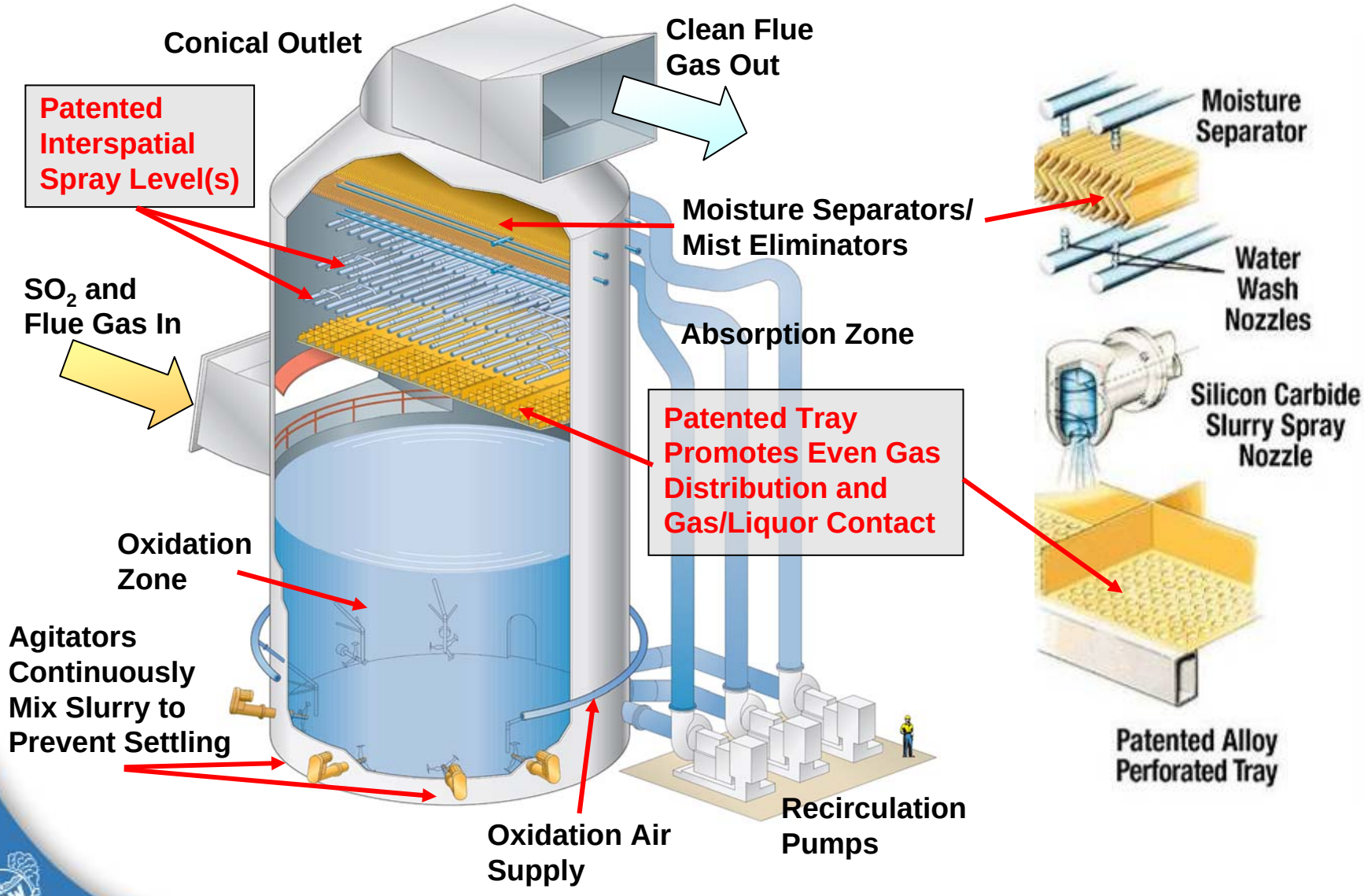
Typical Open Spray Tower



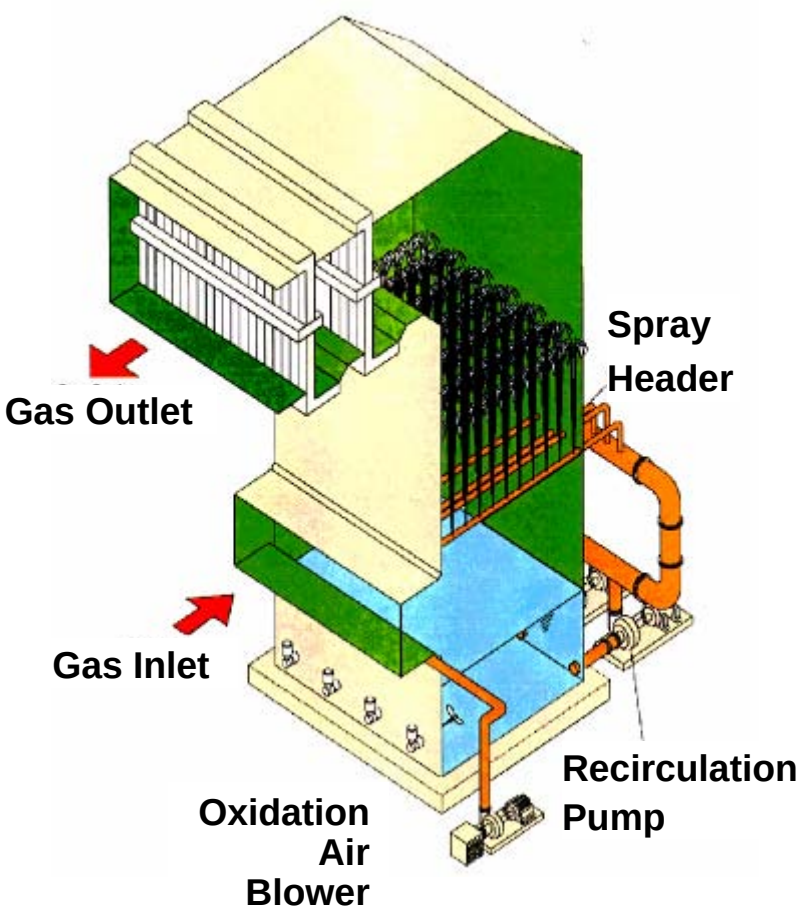
Open Spray Tower

Source:
Babcock Power Inc.

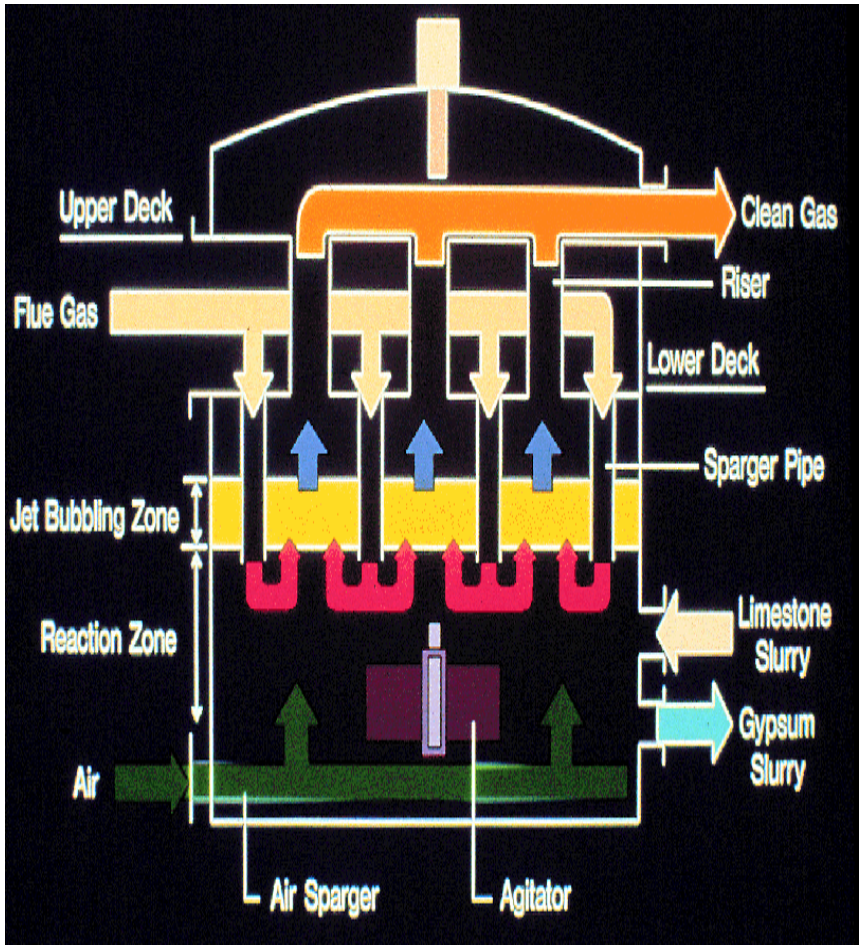
B&W's Wet FGD Absorber

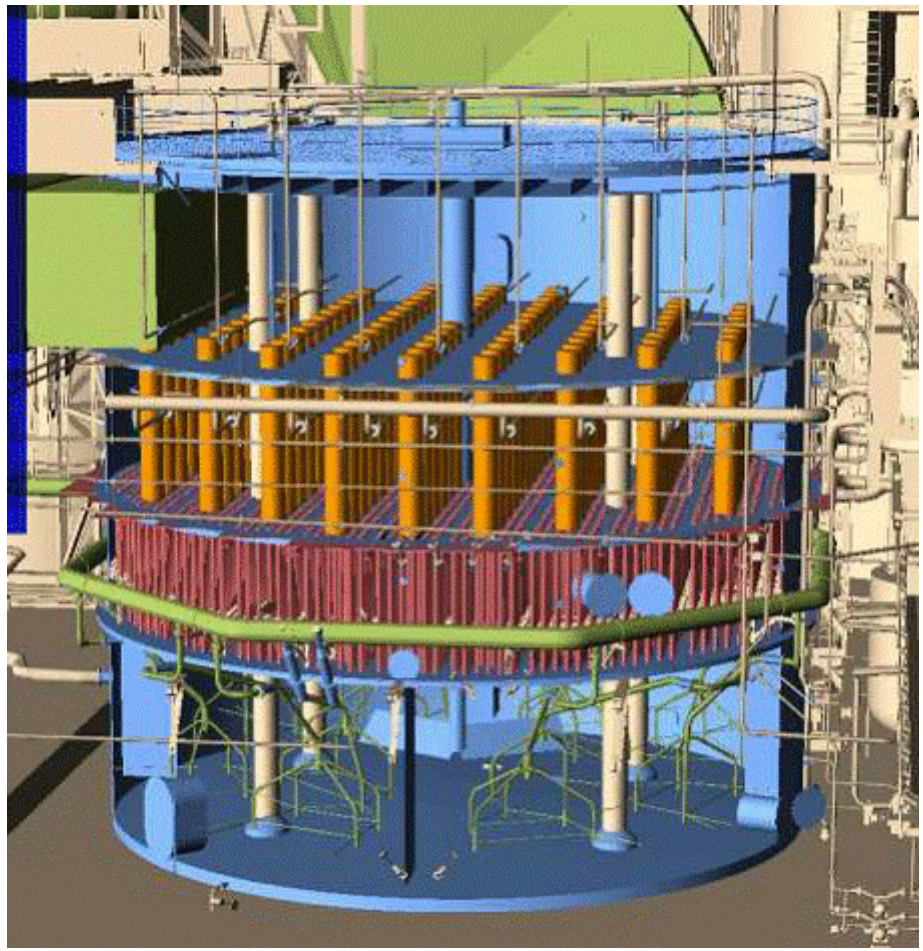


Double Contact Flow Scrubber
MHI - Advatech



千代田化工建設 (Chiyoda) - Jet Bubbling Reactor





Packed Towers No Longer Used

Workshop Outline

1. Wet FGD Process Description, Equipment, Configuration, Materials

- **What's the issue & progress**
- **Overview of major types of utility FGD systems**
- **General description of wet limestone forced oxidized (LSFO) system**
- **Basic types & configurations of commercially available LSFO FGD technology**
- **Absorber Configuration, Equipment, Materials**
- **Forced Oxidation / Dewatering, Milling System**

Absorber Tower Sizing

Diameter or Cross-section

- Set by gas flow
- Set for proper gas contact & to prevent mist carryover
- Usually 10-14 FPS superficial gas velocity, higher with MHI design, lower with Chiyoda

Height

- Gas flow and inlet opening width sets inlet
- Number of headers sets absorption zone height
- L/G & Retention Time sets recirculation tank volume
- Mist eliminator height or depth is fixed

Note: Higher SO_2 removal efficiency and SO_2 inlet concentration increases the required Liguid to Gas Ratio (L/G) and hence increases the number of headers, spray zone height and recirculation tank retention time and volume.

Absorber Gas Inlet

Source:
Babcock Power Inc.

FRP Spray Headers

Alloy Spray Headers

Hollow Cone Spray Nozzle

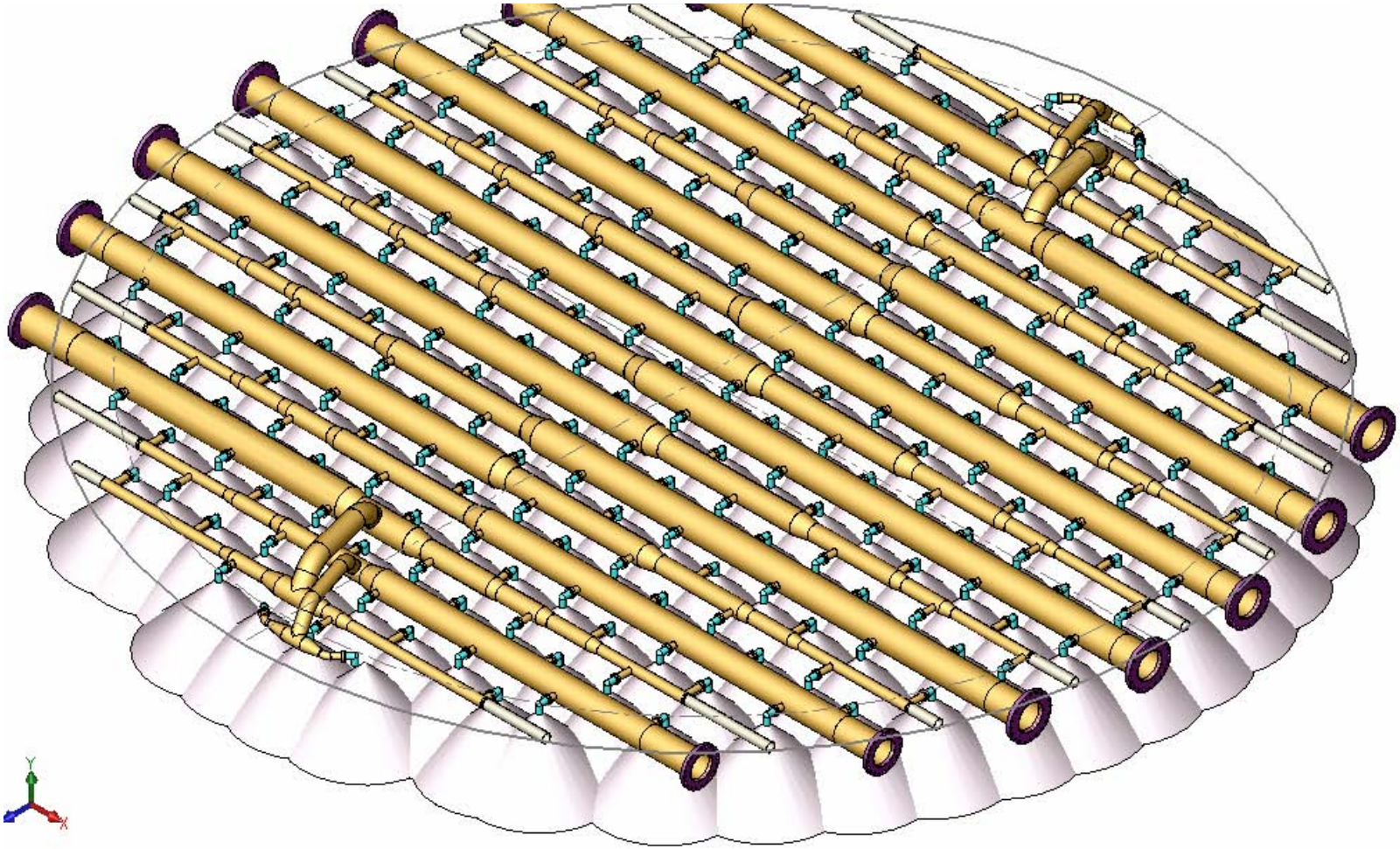
Also top & bottom exit nozzles of this type

Spiral Nozzle

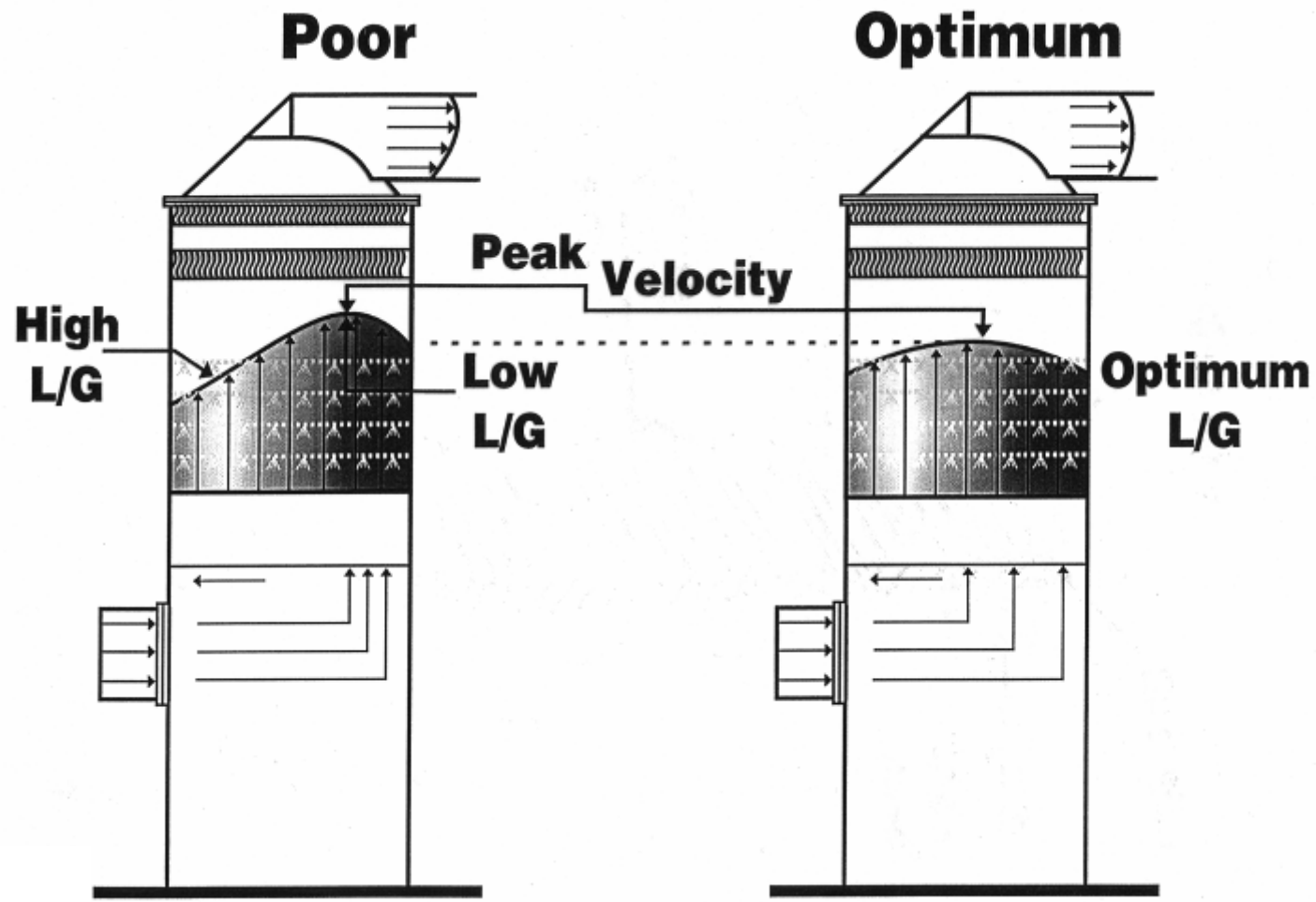
Excellent Spray Distribution, but…

Spiral Nozzles prone to breakage

Spray Headers & Nozzles Full Coverage



Importance of Gas Flow Distribution



B&W Absorber Gas Inlet with Tray

Absorber Spray Nozzles & Tray

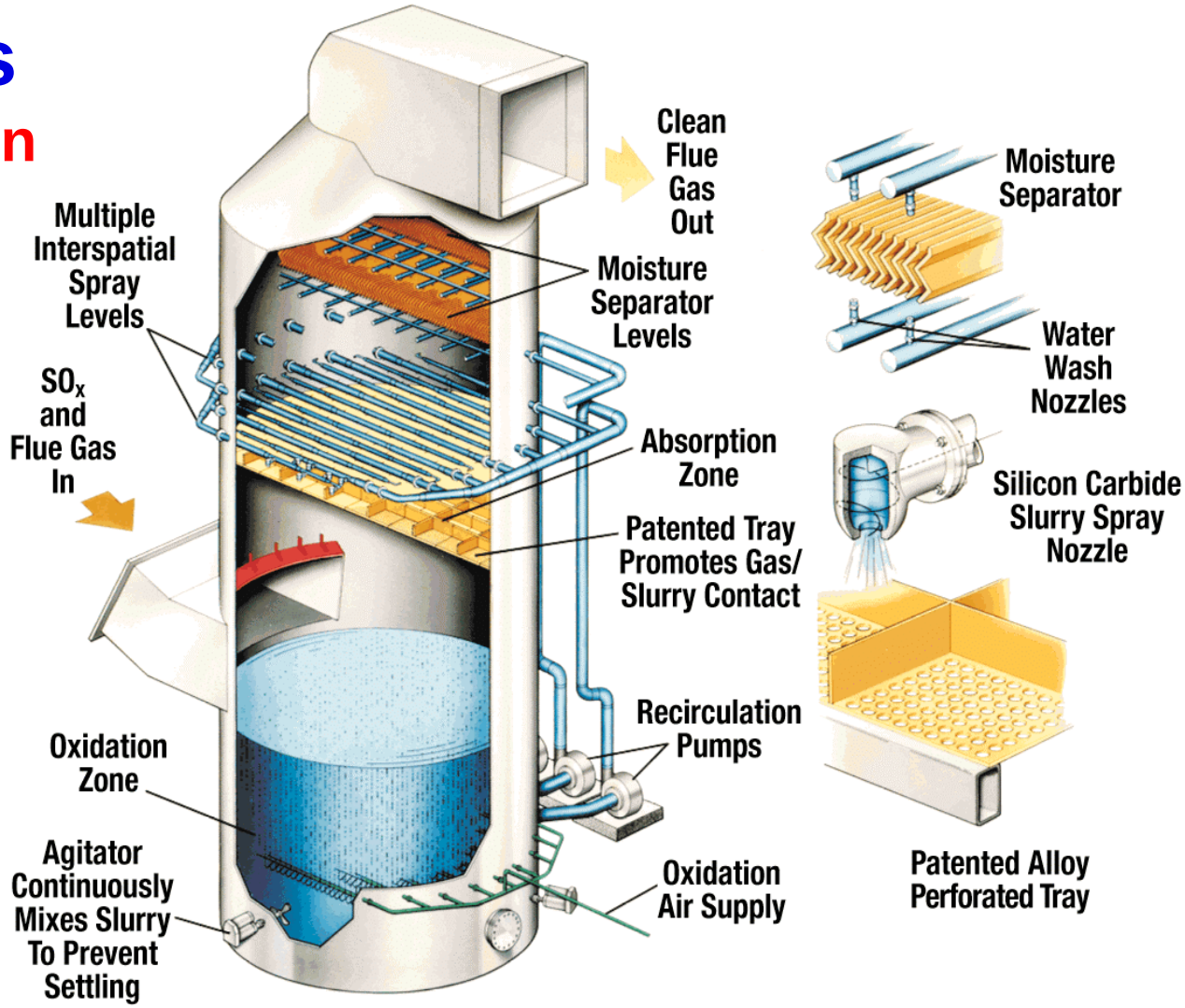
Note the ease of nozzle maintenance

Absorber Spray Headers & Tray

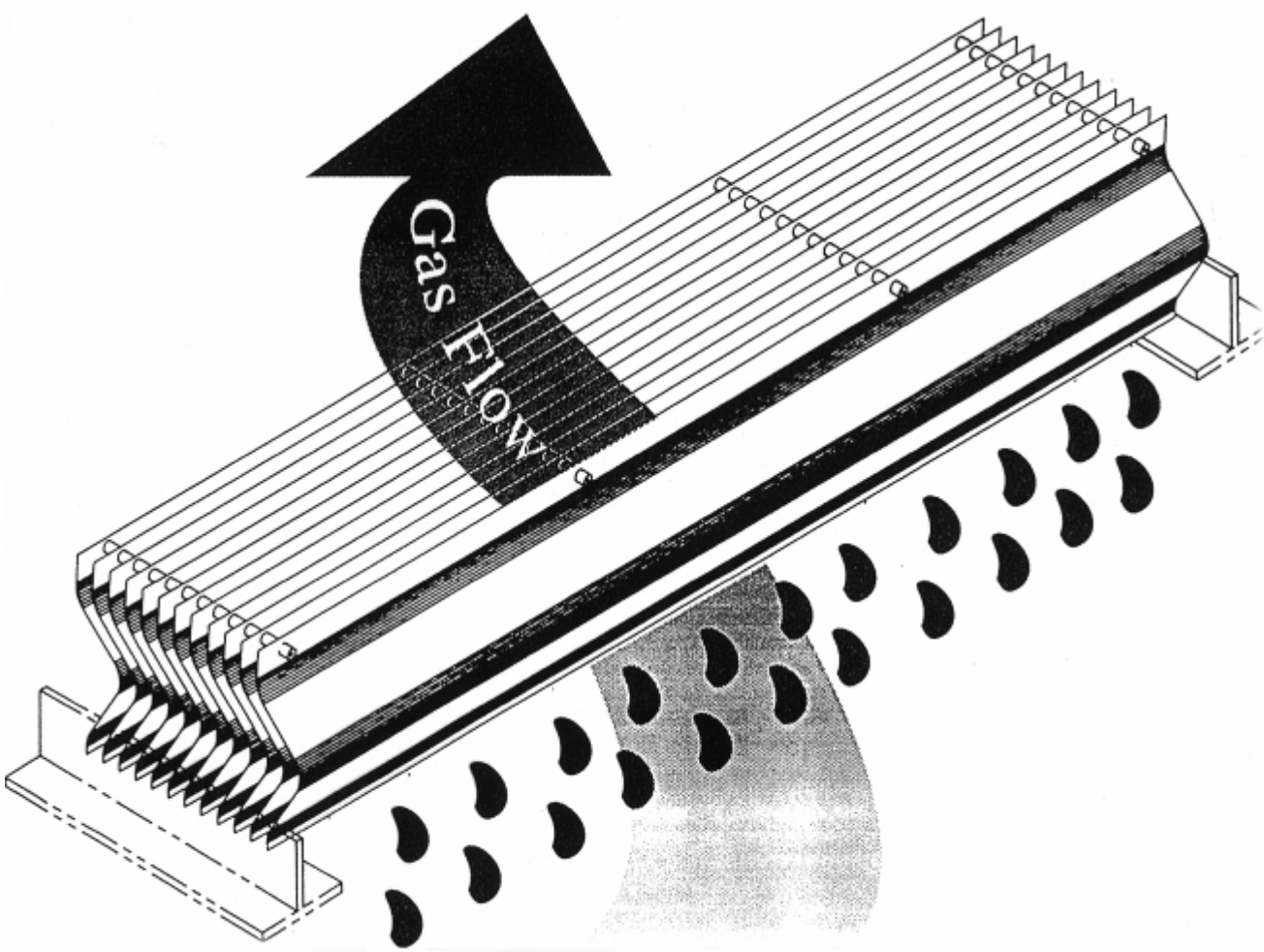
Taiwan Power Unit 5 – One-year Inspection

Absorber Tower Subsystems

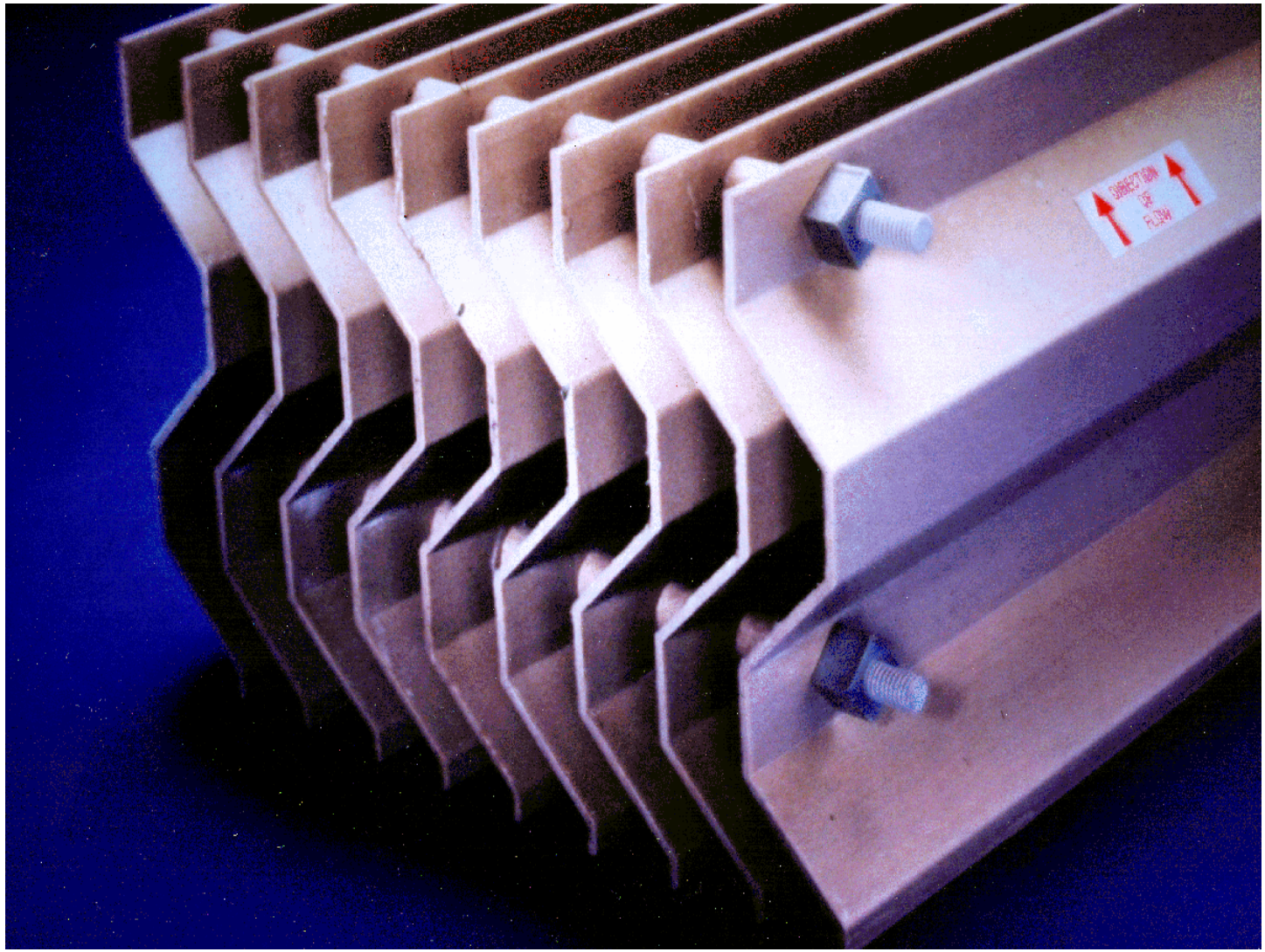
- **Mist elimination**



Mist Eliminator



Mist Eliminator

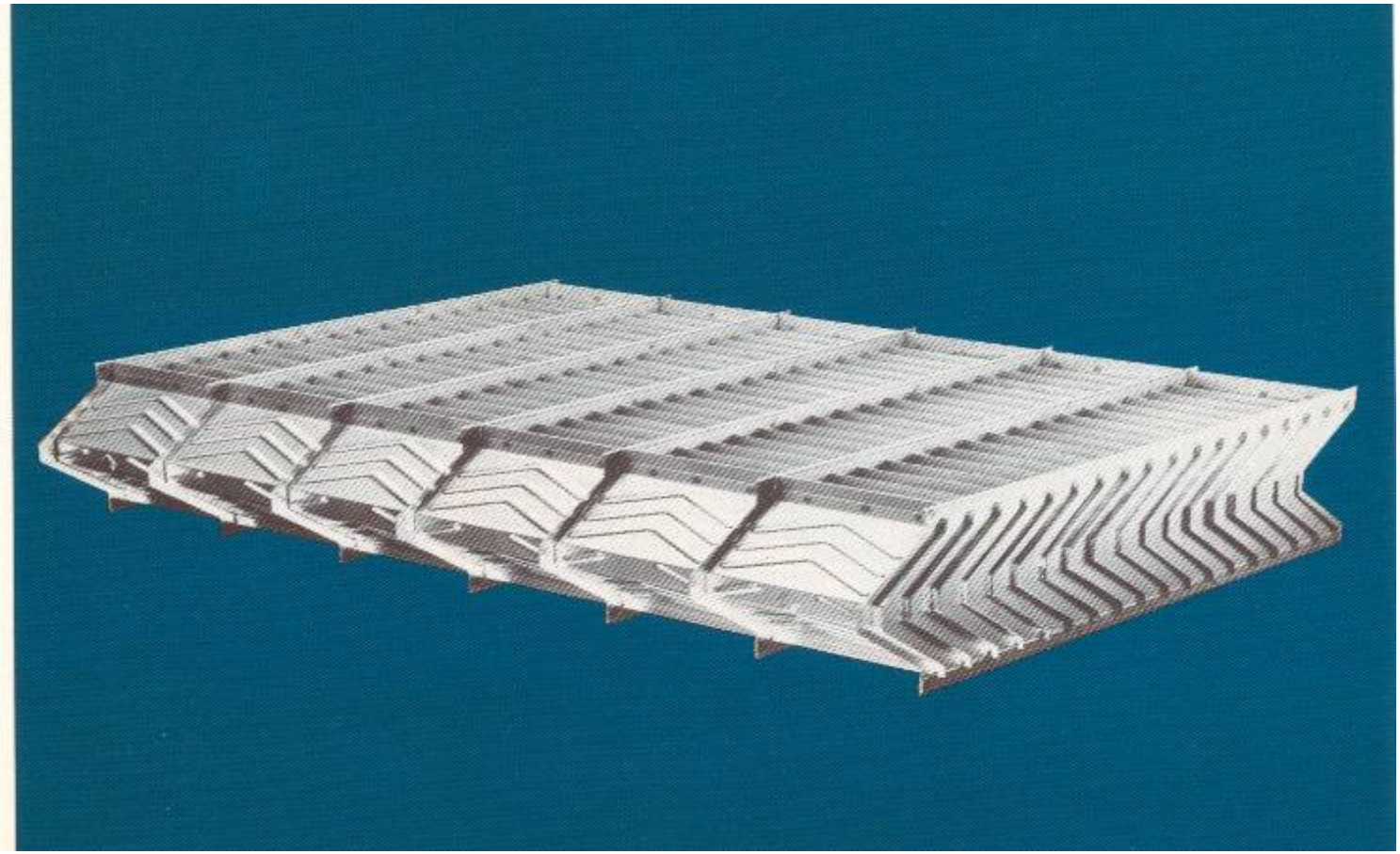


9” to 12” high

Typical Lower & Upper Mist Eliminator

Source: Munters

Mist Eliminator



Source: Munters